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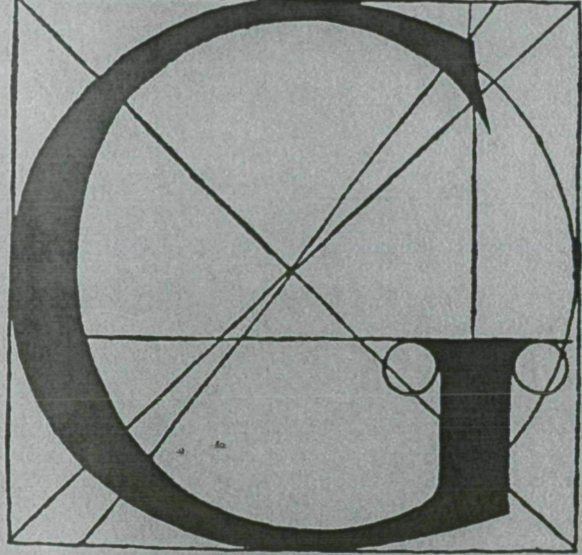

Leonardo drawing of the letter G from "Divina Proportione" Venice, 1509

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Gellman Research Associates, Inc.

THE ECONOMICS OF PRIVATE-SECTOR R&D DECISIONMAKING IN AERONAUTICS

December 20, 1984

Prepared for:

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SECTION I. INTRODUCTION AND SUMMARY

Study Objectives

The purpose of this study is to provide NASA with additional information which it can use in its planning to insure that its commercial research and technology programs are complementary to internally financed private sector activities. The main concern was to identify the characteristics of productive projects that firms are unlikely to invest in; discussions held with industry show that:

- If it is difficult to assess the commercial relevance of an R&D project or if it is characterized by high technical risk, or a relatively long payback period, then it is unlikely to be funded privately.[1]
- If a project is large relative to the size of the firm, then it is unlikely to be funded in the early stages of the R&D process.

Firms tend to "underinvest" in projects with these characteristics.

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[1] Some research may be conducted at the basic level, but very little basic research is done in the private sector.

These results are consistent with a previous study by Gellman Research Associates, Inc. (GRA)[2] and with studies of other industries.

Definition of Underinvestment

The previous study was based upon the existing economics literature and other literature pertaining to aeronautical research and development activities. That study, showed that firms in the aeronautics industry lack sufficient incentives to conduct socially optimal levels of R&D. Often, while industry returns (and other benefits) from particular projects may warrant investment from a social point of view, no single firm can realize sufficient returns to induce it to invest in these projects. This is the underinvestment problem.

Summary of Findings

The results of the study are based upon discussions with the 12 major U.S. aeronautics manufacturers listed in the Acknowledgement Section in the front of this report. The findings can be summarized under three topics:

- o R&D Decisionmaking Criteria.
- o What Can Cause Underinvestment.
- o Likelihood of Firms Funding R&D Activities.

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[2] Executive Office of the President, Office of Science and Technology Policy: "Aeronautical Research and Technology Policy" Volume 2: Final Report [November 1982] Chapter V and Appendix C.

R&D Decisionmaking Criteria

The discussions focused on how private aeronautics firms made decisions to spend their own money on R&D projects. In general, firms looked upon R&D projects in the same context as other investments.

- R&D projects were typically justified by their relevance to products and product concepts defined in the firms' strategic plans. The only exceptions were the few firms that conducted some basic research.
- As with other investments, firms also use return on investment (ROI) criteria for certain R&D activities. Development and some technology demonstrations are subjected to ROI studies. Applied programs are usually too far removed from the market to be evaluated in this way; instead, resources are allocated to applied research activities according to their relevance to the products and product concepts in the firm's strategic plan.

Basic research projects are not justified in terms of the strategic plan or ROI studies. Instead, firms that do basic research treat it as a fixed input.

Most importantly, firms do not allocate significant resources (relative to the size of the firm) to an R&D project unless it is justified in terms of both the strategic plan and an adequate return on investment.

What Can Cause Underinvestment

The results of the discussions with industry are consistent with the factors that can cause underinvestment identified in GRA's earlier study. There are four categories of factors that can cause a firm to forgo an R&D project even when it is productive. Each of these is briefly discussed below.

Problems of Appropriability

A firm may have trouble appropriating the benefits of an R&D project under two circumstances. First, the firm may be unable to assess the commercial relevance of a project. For example, firms are very unlikely to undertake large scale-basic research projects because in the aeronautics industry they are so far removed from commercialization.

Second, a firm may have trouble capturing sufficient benefits to justify an investment because the technology is easily copied or can otherwise be exploited by someone other than the innovator. The relative ease of transfer of military propulsion technologies into civil aviation in the 1950's is one example of this phenomenon.

Technical Risk

The survey findings indicated that the willingness of firms to accept technical risks declined significantly as a project moved through the R&D process. One key objective of applied research and technology demonstration is to wring out most of the technical risk before development takes place. Even at the

applied stage, because the technology is linked to product concepts on which the firm depends, heavy investment in high risk activities is unlikely.

Long Payback Period

The strategic plans of firms extend to between five and fifteen years, depending upon the technology involved. When devoting significant resources to a project however, firms expect earlier payback to be forthcoming. That is, in their return on investment analyses, firms will plan on relatively short payback periods for technology demonstration and development projects. Whether or not these early paybacks are forthcoming will depend upon the market, but few projects will be commercialized if their planned paybacks are excessive.

Large Size of Projects Relative to the Minimum Efficient Size Firm

In general, firms devote significant resources to projects only when they can access their benefits. Very large projects early in the R&D process are virtually unknown. The size of a project that a firm will be willing to undertake at any stage in the R&D process will depend upon the technology involved, and the size of the firm. But, firms show great reluctance to undertake large projects at the basic and applied stage in the R&D process.

Likelihood of Private Firms Internally Funding R&D Activities

With the factors defined, one objective of the study is to provide a framework which can be used to supplement current NASA

decisionmaking. The approach is to utilize these characteristics of projects in order to determine those productive ones which firms are likely to shy away from. Not explicitly considered are the technical merits of any project or its ultimate value in the marketplace. But obviously, the potential productivity of any R&D activity is relevant in both the private and public sectors. Here, the objective is to identify those projects which the private sector is unlikely to invest in; if those projects are productive, then they should be properly considered by NASA.

The results are summarized in Table 1.1. Each cell in the Table defines how firms are likely to react in terms of their willingness to internally fund an R&D project. The Table can be quickly summarized in the following manner:

- o If a firm is having trouble assessing the commercial application of an R&D project or if it is characterized by high technical risk, or a long payback period, then it is much less likely to be funded if it is to take place in the later stages of the R&D process.
- o If an R&D project is large relative to the size of the firm, then it is much less likely to be funded in the early stages of the R&D process.

Of course, a project may be characterized by more than one of the characteristics in Table 1.1, in which case the probability of its being funded is reduced still further.

An example may demonstrate more clearly how the results of the study can be used by NASA. One of the radical new

Table 1.1

LIKELIHOOD OF A FIRM INTERNALLY FUNDING R&D PROJECTS WITH CERTAIN PERCEIVED CHARACTERISTICS

	Inability to Assess Commercial Applications	High Technical Risk	Long Payback Period	Large Size of Project Relative to Size of Firm
Basic Research	Varies*	Varies *	Varies*	Very Low
Applied Research	Low	Low	Varies	Very Low
Technology Demonstration	Very Low	Very Low	Low	Varies
Development	Not Applicable	Very Low	Low	Varies

* Very little basic research is privately funded because the likelihood is high that firms will be unable to assess commercial applications and will face high technical risk and long payback periods. All other things equal, a firm is less likely to fund a basic research project than any other type of R&D activity.

technologies that holds great promise for aeronautics propulsion is structural ceramics. Discussions with industry, however, show that:

- o Firms do not currently include the technology in their product concepts, and therefore cannot assess its commercial potential.
- o The technical risk in commercial figurations would seem to be high; currently, for example, the systems are not reliable for one-time use in cruise missiles.
- o The technology appears to be about 20-30 years from commercialization, well beyond the 15 year duration of even the longest corporate planning horizons.
- o The size of the project at each stage in the R&D process may exceed that which is typical.
- o The technology does not appear to be well enough developed to even hazard a guess as to ultimate capturability of benefits to the first firm to enter the market. But, the present early experiments would seem to have wide applications (including to automobiles), and so are not likely to be capturable solely by aeronautics firms. Indeed, the Japanese are funding a cooperative research program in this area which includes both automobile and aeronautics firms.

These attributes of structural ceramics projects, assuming their technical merit and social value, would seem to make them candidates for NASA funding.

We suggest that the application of these characteristics to other emerging aeronautics technologies will aid NASA in making appropriate funding decisions.

Shown in Table 1.2 are some of the other notable findings of the study. All of these findings are discussed in detail in Section IV, which presents the results of the interview program. In Section II, the theory of private sector R&D decisionmaking is reviewed. Section III reviews the methods employed in the interview program. Finally, the policy implications summarized above are more fully developed in Section V.

Table 1.2

OTHER SIGNIFICANT FINDINGS

- Firms or divisions of large multiproduct corporations that produce engines and helicopters tend to allocate a higher percentage of the internally funded R&D budget to research activities.
- A much smaller percentage of internal R&D budgets is allocated to research by general aviation firms.
- Significantly more basic research is conducted by large, multiproduct firms which are able to apply the results over a broad range of products. However, basic research usually is less than one percent of the internally funded R&D budget.
- Virtually all applied research is tied to the products or product concepts defined in the firms' strategic plans. The results are therefore expected in the near term and firms generally shy away from high risk applied projects for fear of missing objectives defined in the plan.
- Technology demonstrations are carried out (for the most part) only to eliminate technical risk

Table 1.2 (cont.)

in a development program. Technology demonstrations subject to high risk, long payback, and/or unclear commercial relevance are unlikely to be undertaken in the private sector.

- Most strategic plans cover time periods of between 5 and 10 years. Since most R&D is justified in terms of the strategic plans, this suggests that firms tend to shy away from long-term research projects.
- Strategic plans are guided primarily by the firm's perception of which products and product concepts are likely to sell in the market. It is the technical feasibility of these products and product concepts that concern the private firm, not the feasibility of technological advances themselves.

SECTION II. ECONOMICS OF PRIVATE SECTOR R&D FUNDING

Introduction

In this section of the report, the economics of private sector R&D decisionmaking are briefly reviewed. The main focus is on those circumstances in which a firm will choose not to expend its own funds on R&D projects which are productive to society in general. In such circumstances, a firm can be said to be "underinvesting" in R&D. To economists, such situations are termed "market failures"--i.e., instances where the market fails to provide the correct signals for decisionmaking. When market failures occur, government intervention is justified to correct the allocation of resources so that society can benefit from projects that otherwise would not be internally funded in the private sector. Obviously, defining such circumstances is relevant to defining NASA's role in the aeronautics industry.

This section of the report presents the theory of R&D decisionmaking in the private sector, and those problems which can cause underivestment. In order to test for the existence of these problems, GRA discussed with major aeronautics firms their decisions concerning internally financed R&D. The results of the discussions are provided in Section IV and their implications for NASA participation in R&T are reviewed in Section V.

Economics of R&D

R&D is an input into the firm's production activity. As with other inputs--such as labor, capital, interest, etc.--the firm attempts to optimize the use of R&D in order to maximize its profits. In theory, the firm increases its R&D activity until the marginal benefit received equals the marginal cost incurred.

The benefits of R&D are defined in terms of the technical enhancements to the firm's products and ultimately by their market value. Ideally, the firm would like to know the marginal revenue product of each additional unit of R&D; ideally, it would like to measure the change in its revenues due to the expenditure of an additional hour of a scientist's time on a given project. If the marginal revenue product of a scientist's time exceeds the firm's costs, then it makes sense to allocate an additional hour of the scientist's time and related resources to the project; if the reverse is the case, then the project should be avoided or discontinued. Obviously, such theoretically correct evaluations are difficult in the real world, but the closer the firm can come to realizing such measurements,[1] the more likely it is that it will be able to optimize the production of R&D--equalizing marginal benefits and costs.

A more familiar way to view appropriate criteria for making R&D and other investment decisions is to note that it is

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[1] Here we are assuming the costs and benefits of collecting information have been optimized.

the firm's objective to maximize its long term net present value. Given its finite resources, it attempts to select projects with the highest returns on investment (ROI), which in turn maximize the value of the firm for its stockholders. In formal planning studies, most large firms attempt to make such ROI evaluations, which involve forecasting the timing of costs and revenues and taking account of alternative opportunities for the resources deployed. These ROI studies are the real world approximations of the theoretical measures discussed above.

The Underinvestment Problem

There are reasons to believe that private sector decisionmaking with regard to R&D may not always be socially optimal. There may be cases where R&D projects have an adequate return to society, but inadequate returns for a single firm. In such cases, firms are said to be "underinvesting" in R&D, from society's standpoint. This conclusion is not meant to disparage the private sector; in fact, there is every reason to suspect that each firm is rational in pursuing its R&D activities. Rather, these cases where underinvestment exists or is likely to exist are logical candidates for government activity, so that society can realize the benefits of projects which are productive to society and otherwise would be underfunded by the private sector alone.

There are many reasons why firms may underinvest in R&D activities. One example may clarify the point, however. Suppose

a firm considers a project whose costs are $8 million and where benefits (to the firm) are $10 million.[2] Given these circumstances, the firm would be likely to invest. Now suppose the firm finds it can only realize (or "appropriate") $7 million in benefits because a competitor will be able to copy the results of the project at little or no cost and thereby realize the remaining $3 million. Under these circumstances, the firm would be unlikely to invest its own funds. Nevertheless, some form of government participation could make the project attractive enough to the innovating firm to undertake the project and thereby allow society to realize benefits which otherewise would be lost. This is one example of the underinvestment problem and how government participation can ameliorate it.

Underinvestment in R&D Can Be Caused By Appropriability Problems

There are two related kinds of problems which can arise in R&D activities that make it difficult for a firm to capture sufficient benefits to justify a project that is otherwise attractive to society. These "appropriability" problems that can cause underinvestment are:

- o Problems in assessing the commercial value of R&D.
- o Problems in capturing the benefits of R&D.

Each is discussed in turn below.

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[2] We assume these costs and benefits are discounted appropriately.

Problems in Assessing the Commercial Value of R&D

One problem that can arise in R&D activities is that a firm can sometimes have difficulty identifying the commercial relevance of a project. The less clear the commercial relevance--i.e., the less it can be directly related to the firm's current or planned products--the less decisionmakers are able to evaluate the potential benefits of the R&D activity. Obviously, there are gradations of this problem. An exercise in pure mathematics will be more difficult to assess than a wind tunnel test of an airfoil which in turn is more distantly related to commercial activities than an initial flight test of a new commercial aircraft. Given the fact that a firm will have limited resources, it is likely to devote more of these resources to activities it can assess well.

Problems in Capturing the Benefits of R&D

Another problem of appropriability springs directly from the nature of some technology; there are two relevant types: "neutral" and "proprietary" technology.

Proprietary technology includes activities for which individual firms are able to capture a return sufficient to justify investing in an R&T project. Developmental activities--e.g., developing a specific aircraft for commercial use--could be regarded as proprietary. A firm decides to pursue a product development because it believes it can capture sufficient

benefits from these activities. The firm therefore will be able to make straightforward investment decisions with regard to proprietary technology.

In contrast, neutral technology represents R&T activities on which it is difficult, and sometimes impossible, for individual firms to earn proprietary rates of return sufficient to economically justify initial investment costs. This problem occurs either because large investments in facilities are necessary to undertake such R&T activities or because the R&T benefits flow to other concerns, in either the same industry or other industries. Neutral technology is a common base for several different firms, for several reasons:

- Knowledge is expensive to produce but cheaper to reproduce. A firm or institution that creates knowledge sometimes must incur substantial expenses, but others may reproduce, imitate, or learn the knowledge at relatively low cost.
- Use of the patent system to appropriate returns from R&T is difficult and costly in the aeronautics industry because technological advances often depend on knowledge of specific processes--e.g., supersonic flow in aeronautics--instead of some mechanical or electronic device.
- While knowledge that flows from R&T efforts is a commodity in the sense that it embodies some value, it is unique because it may be reused, both by the

innovator and by those who learn it, without diminishing its value in production. Therefore, apart from the relatively minor expense and low risk of learning new knowledge, it is as valuable to the imitator as to the innovator, at least in terms of its value in production.

Where neutral technology is involved, each firm pursuing its own maximum profits will invest in these R&D activities only until its own marginal benefits equal marginal costs. However, the productivity, and hence efficiency, of other firms in the industry is influenced by this R&D decision. For example, each dollar of R&D not undertaken by Firm A reduces Firm B's productivity (as well as the productivity of other firms in the industry). Firm A, however, considers only its own return on R&D, and not the returns of others in the industry, in making R&D investment decisions. In short, Firm A will tend to underinvest in R&D because it cannot capture all the benefits derived from its own R&T projects.

If each firm recognized spillover benefits to industry rivals, and also had the altruistic motive of maximizing total benefits flowing from R&D instead of just those that are privately captured, all firms would increase the level of R&D output and thereby increase the total amount of benefits flowing from R&D efforts to the socially optimal level. Since firms typically do not have such altruistic motives, they are likely to underinvest in neutral technology.

Sections IV and V contain examples of those projects likely to have neutral technology characteristics. Obviously, in actual markets, the problems relating to neutral technologies are a matter of degree. But, this concept and the resulting "under-investment in R&D" are central to defining NASA's (the government's) role in R&D.

Underinvestment in R&D Can Also be Caused by Problems Associated with Risk, the Payback Period, and Scale Economies

Other problems can also arise due to risk, long payback periods, and the scale economies associated with some research. These problems are illustrated briefly below.

Risk

Suppose a firm is considering a potential R&D project and the cost of the project is known with certainty to be $8 million. For the sake of simplicity, further assume only two outcomes are possible: the R&D project will yield zero benefits, or the R&D project will yield total benefits of $20 million. If the two outcomes are equally probable, then the expected payoff from the R&D project will be $10 million. This expected payoff is sufficiently large to cover the certain costs of the R&D project, and will produce an expected net benefit of $2 million. Nonetheless, the consequences of failure may be unacceptable to the firm. Thus, even when a firm can accurately assess the benefits of R&D, aversion to risk can cause it to forego productive R&D.

Risk is directly related to the size of a project; the larger the downside potential, the greater the aversion to a project is likely to be. Standard portfolio-selection theory provides some useful insights into the types of incentives firms have to conduct risky R&D projects. If the probability distribution characterizing the range of possible outcomes flowing from an R&D project is "well-behaved," then firms can reduce risk by diversifying into a large number of relatively small propjects. If, however, the nature of the industry is such that diversification into a large number of small projects is not feasible, then risk reduction through diversification will not be feasible. Consider two firms, A and B, each having a net worth of $10 million. Suppose further that Firm A, because of the nature of the market within which it operates, can conduct 10 separate R&D projects, each costing $1 million. Firm B, on the other hand, has only one R&D option, a $10 million project. Even if the expected payoff from the R&T activities of each firm is the same, Firm A, by diversifying into several smaller projects, will face considerably less risk than Firm B. Thus, the size of an R&D project affects a firm's willingness to undertake it.

Payback Period

The payback period can be defined as the interval between the time at which expenses in a particular project are first incurred and the time at which sufficient revenues are obtained to achieve a break-even point. From the perspective of the

owners or stockholders in a particular firm, the payback period, in isolation, should not influence a firm's incentive to undertake investment projects. Standard economic theory states that, regardless of the timing of returns on a project, it should be undertaken as long as it increases the net present value of the firm. Moreover, should they require cash, the owners of a firm theoretically can sell their assets at any time for a market price reflecting the assets' discounted value. However, two factors complicate the payback-period issue: management incentives to undertake projects with relatively short payback periods, and the relationship between the payback period and risk.

Much recent literature has focused on the problem that R&D projects typically have lengthy payback periods, while management has incentives to undertake projects with relatively short payback periods. At almost any level in the management hierarchy of a given firm, promotion opportunities for individuals depend on their short-term performance. For example, basic research, which is the furthest removed from commercial exploitation, is the least likely to be undertaken, given the short-term incentives of management.

The payback period and risk are also related; that is, the longer the payback period for a particular project, the greater the risk or uncertainty embedded in the project. Suppose it is known a particular project will have a payback period of 20 years. Even if the firm is certain this R&T project will yield significant benefits in terms of today's markets, it will face

considerable uncertainty regarding the value of those benefits 20 years hence. Uncertainty regarding both market demand for the product, as well as market conditions for necessary productive inputs, may cause the firm to forego a productive investment opportunity.

Problems of Scale in R&D

The existence of significant scale economies may also make it difficult for individual firms to realize sufficient private return on neutral R&T. Often, R&T requires large capital-intensive facilities--e.g., wind tunnels, flight test facilities, propulsion facilities and special capability facilities. The returns capturable by a single private firm are often not sufficient to justify extensive investments in these capital-intensive facilities. If the facilities are not otherwise available outside of the firm, some productive R&D will be foregone by the private sector.

Summary

A number of circumstances can interfere with a firm's willingness to undertake productive R&D projects. They are:

- Difficulty in assessing the commercial value of a project.
- Problems in capturing the benefits of a project.
- Problems of scale.
- High risk.

- Lengthy payback period.

In the foregoing discussion, the problems have been highlighted separately. A firm will typically find, however, that more than one of these problems will characterize a particular project.

In order to evaluate how these problems affect internal funding of commercial aeronautics projects in the private sector, discussions were held with the major commercial aeronautics manufacturers in the U.S. The format of these discussions is described in Section III.

SECTION III. FORMAT OF DISCUSSIONS WITH INDUSTRY

As part of our research we held discussions with 12 commercial aeronautics companies in the United States. The results of these discussions and their implications are reported in Sections IV and V. The format of these discussions is reviewed below.

Objective of Discussions

Section II covered the problems firms sometimes have in undertaking certain types of R&D investments. A more thorough review of the theoretical principles underlying these problems is contained in our report to the Office of Science and Technology Policy contained in "Aeronautical Research and Technology Policy" (Volume 2, Appendix C, November 1982). In that report, GRA also provided analytical information based on published literature. In this study, we wanted to further test our hypotheses by holding discussions with key decisionmakers whose responsibilities included development of aeronautics R&D budgets and their allocation among different R&D types. The purpose of the discussions was to uncover how these decisionmakers handled various problems identified in the previous study and summarized in Section II of this report. Ultimately, this information would provide further guidance in defining NASA's role in commercial

R&T, and in identifying the characteristics of productive projects in which the private sector is likely to underinvest.

Structure of Discussions

The discussions can be loosely divided into four general areas. The first objective was to identify the operational definitions of R&D used by these firms in their planning. This involved relating their internal definitions of R&D activities to those used by NASA, and DOD, and those found in the general literature. This was necessary to distinguish between types of research--i.e., basic, applied, technology demonstration and development projects. It was important that these distinctions be made not only because each firm's decisionmaking processes would be different, but also because funding sources and budgets could also be different.

With the general definitions out of the way, the second part of the discussions explored funding sources for the various R&D activities. Here, it was especially important to segregate out the firm's own internally financed R&D activities (including IR&D) from outside funding sources including DOD and NASA. A firm's behavior is likely to be colored by the degree to which its R&D is funded from the outside if only because it loses some control over the types of R&D activities in which it is engaged. But obviously the most important aspect of this phase of the discussions was to focus attention upon that portion of the R&D budget over which the firm had complete discretion. Its behavior

with regard to these internal R&D budgets would help to define those projects in which the private sector is likely and unlikely to become involved.

The third phase of the discussions focused more specifically on the decisionmaking process of the firm and the general criteria used to establish internally financed R&D budgets. The focus was on individual types of R&D activities and how budgets were allocated to each. This amounted to a discussion of the firm's strategic planning activities as well as its short-term budgetary procedures. The criteria used to allocate funds to different research and development categories are directly relevant to the characterization of the firm's R&D investment decisionmaking.

Finally, the fourth stage of the discussions focused on the methods and criteria used to allocate budgets to specific projects. It was in these discussions that the decisionmakers revealed their approach to handling the problems that can lead to underinvestment in R&D.

Participating Firms

The discussions were held with 12 civil aeronautics firms over a four month period in early 1984. The companies that agreed to participate were:

- Boeing Commercial Airplane Company, Division of the Boeing Company,
- Boeing-Vertol Company, Division of the Boeing Company,

- Douglas Aircraft Corporation, Division of McDonnell-Douglas Corporation,
- Lockheed-California Corporation, Division of the Lockheed Corporation,
- General Electric Aircraft Engine Group, Division of General Electric Corporation,
- Pratt & Whitney Group, Division of United Technologies Corporation,
- Sikorsky Aircraft, Division of United Technologies Corporation,
- Bell Helicopter, Division of Textron, Inc.,
- Gates Learjet Corporation,
- Beech Aircraft Company,
- Cessna Aircraft Company,
- The Garrett Corporation, Subsidiary of the Signal Companies.

All of the participants were extremely forthcoming and helpful in providing information for the study. In general, each of the discussions lasted between two and three hours. Follow-up discussions were held as necessary to clarify various technical points.

SECTION IV. INTERVIEW RESULTS

Introduction and Summary

Detailed descriptions and interpretations of the responses obtained in the interviews are provided below in this section of the report. What follows is a summary of the survey results.

One of the key concerns with regard to the NASA Aeronautics Research and Technology Program is that it not duplicate research that is or would otherwise be done in the private sector. The discussions with industry representatives were designed to identify the decisionmaking processes used by civil aeronautics firms to fund their own (internally financed) research. By identifying the characteristics of projects the private sector will typically fund, we hoped to identify the characteristics of any remaining productive projects that NASA should consider funding.

All aeronautics firms in our sample develop strategic plans which define their current products and their product concepts for the future. Investments in these products and product concepts are subject to return on investment (ROI) studies. These ROI studies become more detailed and rigorous, the greater

the resources devoted to a project. In fact, no firms in the sample will devote significant resources to a project without an ROI study.

Internally funded R&D projects require investment of firm resources. These projects typically support the products and product concepts in the strategic plan. However, firms find it more and more difficult to apply ROI criteria to R&D projects the further the projects are removed from near-term commercialization. In general:

- o Firms are able to assess the likely returns on investment on development projects. If a development project meets a firm's hurdle rate of return and supports the products or product concepts in the strategic plan, it will devote resources (sometimes significant resources) to the project.
- o Most applied research is tied directly to the objectives of the strategic plan, and is undertaken to reduce or eliminate technical risk in specific programs. However, firms usually cannot identify a specific rate of return on applied research programs. As a result, firms typically do not devote significant resources to any one applied research project.
- o A minority of the firms in the sample performed some basic research. They tended to be large, multiproduct firms that had a greater likelihood of realizing the benefits of basic research. None of these firms could

evaluate the rate of return on basic research, and only sometimes could relate it to specific objectives in strategic plans. Instead, most of these large, diversified firms looked on basic research as a fixed input to which a small percent (usually less than one percent) of the firm's <u>own</u> R&D budget is devoted. Typically, basic research projects are very small; firms attempt to have many small basic projects going at once in order to spread risks.

- Most firms perform technology demonstrations only if there is no other way to reduce or eliminate the risk in a project. Demonstrations are always tied directly to the objectives in the firm's strategic plan, and many firms are able to perform ROI analyses on them.

In summary, resources are allocated to all basic and most applied research based primarily on technical criteria. Firms have great difficulty evaluating the economic returns to either type of research. Applied research is generally guided by the objectives in the strategic plan, while basic research is usually not tied to any specific product or product concept.

In contrast, development activities are always subject to strict economic criteria and tied directly to the objectives of the strategic plan. Firms will only allocate the significant resources required for a development program when sufficient

returns are forseen. Technology demonstrations have similar attributes, although the economic criteria are sometimes more difficult to apply

As was explained earlier, the interviews were divided into four main topics:

- o Definition of R&D activities.
- o Funding sources.
- o Internal R&D budget allocation procedures.
- o Criteria and methods employed to evaluate individual research projects.

The discussion that follows is organized to be consistent with the structure of the interviews; that is, each of the four central topics listed above is discussed in turn.

Definitions of R&D Activities

In this first section of the interview, an attempt was made to establish agreed upon definitions of different R&D types that would be the basis of later discussion in the interview. Next, representatives of private sector firms were asked to identify the extent to which their respective firms conducted each of the different R&D types. Following this, they were asked to identify important sources of external funding for R&D activities. Finally, the interview subjects were asked to describe internal R&D funding arrangements.

At the beginning of the interviews, industry representatives were asked if they were comfortable with the following typical distinctions between different types of R&D:

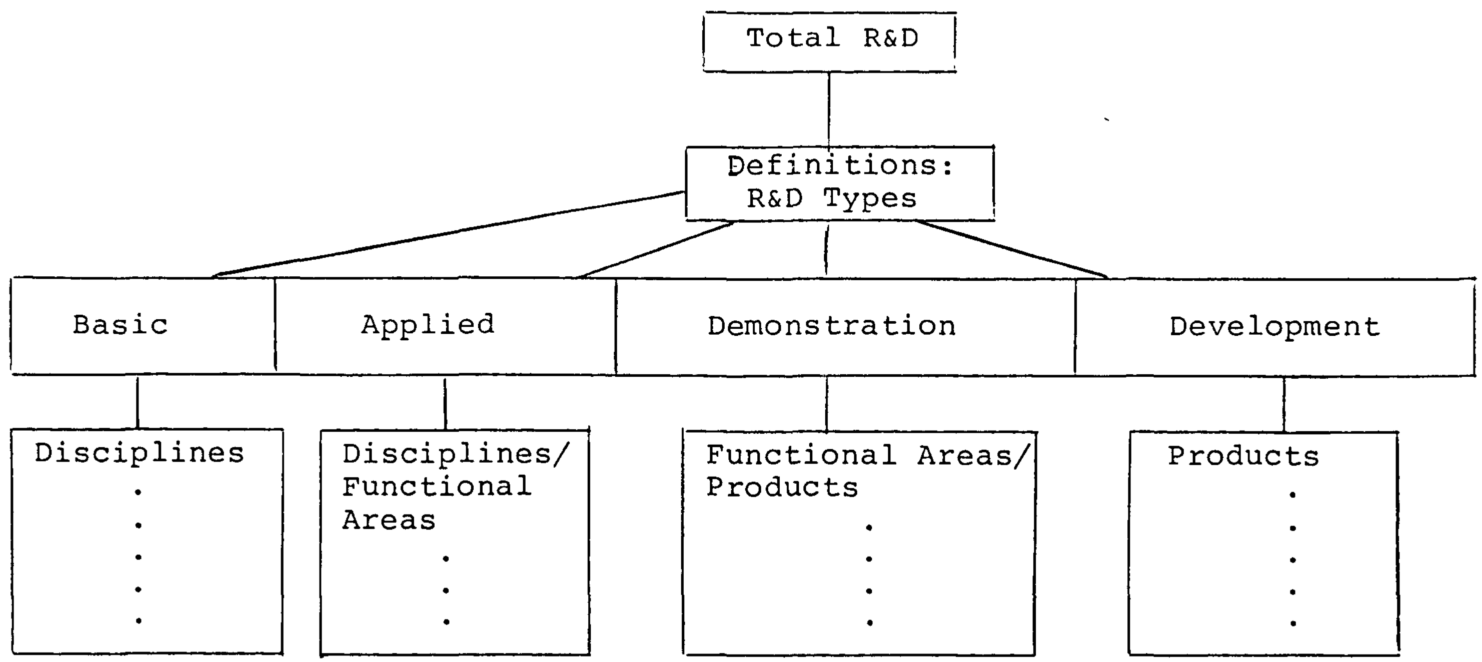
- Basic Research--obtain knowledge or understanding of a phenomenon (which might be relevant to an application).
- Applied Research--determine whether certain performance can be achieved under at least some laboratory conditions.
- Demonstration--determine that the new technology is feasible in that the desired performance can be obtained outside a laboratory setting (e.g., through the use of a scaled-down model).
- Development--construct a prototype working model which embodies the new technology.

Next, the interview subjects were shown the schematic presented in Figure 4.1. The bottom row of boxes in this figure attempts to identify the types of activities associated with each of the R&D types. It was emphasized that a given R&D project may cross over one or more of the R&D types; that is, it may not be possible in all cases to fit individual R&D projects neatly into any one of the boxes depicted in Figure 4.1.

In virtually all cases, interview subjects claimed no difficulty in relating to the definitions of different R&D types that were offered to them. Although it is difficult to ascertain the precise degree to which different interview subjects interpreted these definitions consistently, we found no evidence

Figure 4.1

R&D ACTIVITIES



that significant misunderstandings existed. Mansfield et al. (1971) made similar distinctions between R&D types in interviews he conducted with private sector firms; he concluded, as we did, that there was no evidence that respondents had significant difficulty interpreting the different definitions.[1]

Indeed, all of the interview subjects agreed that similar distinctions between different R&D types were made within their own firms. Often, however, different names were used for different R&D types (that is, different from the names we offered). In some cases, the interview subjects' nomenclature for R&D types was used to facilitate the administration of the interview.

There was, however, one notable exception to agreement on the definitions of R&D types that were offered. Specifically, several respondents noted that technology demonstration often requires that use of large-scale models, rather than the use of scaled-down models suggested in our example. They explained that often the only feasible way of reducing the uncertainty associated with a new technology is to test it on an experimental aircraft while in flight.

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[1] Mansfield used definitions of different R&D types proposed by the National Science Foundation, 1965. The National Science Foundation definitions distinguish between basic research, applied research and development, but do not distinguish technology demonstration.

Internally Funded Research as a Proportion of Internal R&D

Next, the interview subjects were shown the schematic illustrated in Figure 4.2. We explained that our primary interest was in those research activities that were internally funded.

Industry representatives were then asked to estimate the proportion of internally funded R&D devoted to research. The results are summarized in Table 4.1. Four of the respondents indicated that internally funded research represents about 10 to 15% of total internally funded R&D. Nine of eleven respondents fall within the 10 to 33% range. It is important to recognize, however, that many of the subjects we interviewed represented subsidiaries or divisions of parent corporations. Accordingly, corporate-wide allocations may differ from those figures reported in Table 4.1. This may be especially true for firms with large divisions or subsidiaries that produce products and conduct R&D for the military, or for those corporations that produce a wide-range of other products that may be unrelated to the commercial aeronautics market. In addition, four of the representatives indicated the existence of a corporate research laboratory. Expenditures on research at these corporate-wide laboratories are not included in the figures reported in Table 4.1.

It is important to note that the figures reported in Table 4.1 reflect typical or average ranges in budget allocations between research and development. In practice, the ratio of expenditures on research relative to development varies over the

Figure 4.2

R&D FUNDING

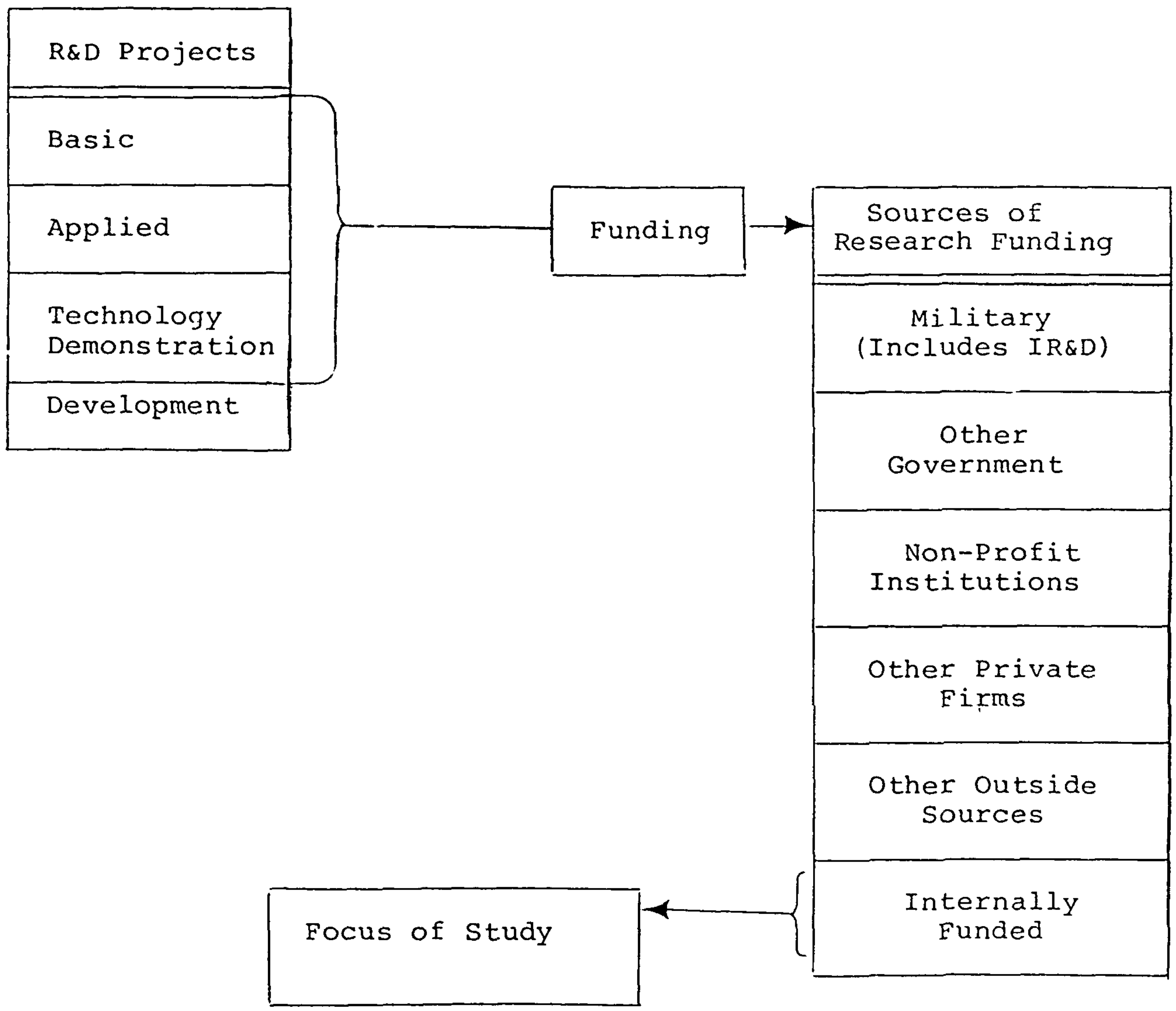


Table 4.1

INTERNAL R&D BUDGETS:
ALLOCATIONS BETWEEN RESEARCH AND DEVELOPMENT

Percent R to Total Internal R&D*	Number of Responses
10-15	4
20-33	5
40-50	2
Total **	11

*Some respondents are divisions or subsidiaries; corporate-wide figures may differ from those reported.

**One respondent did not provide an estimate

product development cycle. Expenditures on development activities increase when firms decide to introduce major new products into the market. In addition, some firms transfer research personnel to development-related tasks during key phases of the development cycle, thus reducing expenditures on research.

There were some notable relationships between the characteristics of the firms and the ratio of internally funded research to total internally funded R&D. Specifically:

- o Firms that focus primarily on general aviation markets tend to have a relatively low ratio of internally funded research to total internally funded R&D.
- o Large multi-product firms tend to have moderately higher ratios of internally funded research to totally internally funded R&D.
- o Firms/divisions that produce engines and helicopters tend to have the highest ratio of research to internally funded R&D.

Proportion of Internally Funded Research Accounted for by Basic, Applied, and Technology Demonstration

Next, industry representatives were asked to estimate the percent of the internally funded research budget allocated to each of the three research types--i.e., basic research, applied research, and technology demonstration. Only three of the respondents, however, were able to provide estimates that distinguished between applied research and technology demonstration. This may have been due, in part, to substantial cyclical

variations in expenditures on technology demonstrations. It appears that major demonstration projects are typically funded when the firm attempts to reduce the technical risk associated with a new technology that it wants to incorporate in a new product. As a result, demonstration activities related to technology validation are often sensitive to the product development cycle.

Table 4.2 provides a summary of the estimates of the percent of the total internally funded research budget that is allocated to basic research. As this table indicates, a relatively small proportion of the total research budget is allocated to basic research. Eight of the respondents indicated that their respective firms, divisions, or subsidiaries do virtually no basic research. The other four estimated that basic research constitutes between 5 and 10% of their total internally funded research budget. Thus, applied research and technology demonstration receive between 90 and 100% of all internal funds allocated to research.

Given the estimates of the percent of research to the total internal R&D budget provided in Table 4.1, it appears that basic research, on an average, receives less than 1% of the total internally funded R&D budget.

Again, it is important to note that the figures reported in Table 4.2 may not reflect corporate-wide trends in budget allocations. For example, those respondents representing firms which had corporate-wide research laboratories indicated that these

Table 4.2

INTERNAL RESEARCH BUDGETS:
ALLOCATIONS TO BASIC RESEARCH *

Percent Basic Research to Total Research	Number of Responses
Virtually None	8
5-10	4
Total	12

*Some respondents are divisions or subsidiaries; corporate-wide figures may differ from those reported.

labs do primarily basic research. These figures are not reflected in Table 4.2. Three of the respondents that did no basic research themselves indicated, for example, that they sometimes sponsor basic research at corporate research laboratories.

When corporate-wide laboratories are considered, large multi-product firms appear to fund significantly more basic research. This result is not surprising. First, and perhaps most obviously, large firms have greater financial resources to fund research projects. Second, and perhaps more importantly, these firms produce a wide range of products and are thus better able to appropriate more of the benefits associated with research. This is especially true for basic research since, *a priori*, one would expect a wide range of applications of basic research, at least relative to more applied research where the potential for application across a wider range of products is limited. Thus, the ability of firms to appropriate the benefits of basic research appears to affect their inclination to fund internally basic research projects.

Funding Sources

The preceding discussions focused on making distinctions between internally funded R&D and externally funded R&D. The second phase of the discussion then turned to funding sources both within and outside of the firm.

External Funding Sources

The interview subjects were asked to identify the sources and extent of external funds available for financing R&D projects. The following sources of outside funding for R&D projects were identified:

- o NASA
- o U. S. Military
- o Foreign Governments
- o The Federal Aviation Administration (FAA)

In addition, some representatives indicated that their research departments, on rare occasions, did research that was financed by other private-sector firms. They indicated, however, that such funding was inconsequential relative to their total R&D activities.

The extent to which external R&D funds are typically available to the representatives of firms, subsidiaries, and divisions interviewed, are summarized in Table 4.3. As this table suggests, a wide range of variation in the sample is observed. Three of the respondents indicated that external funding represented a very small percent (i.e., one percent or less) of total R&D. These firms indicated that, while they generally viewed the externally funded projects as being significant, the total impact on the R&D budget was negligible. Those representatives of divisions or subsidiaries that received a substantial amount of external R&D funding--usually from the military--stated that relatively wide swings in externally

Table 4.3

EXTERNAL R&D FUNDING SOURCES

Percent Funded Externally*	Number of Responses
Very Small (1% or less)	3
5-10	1
20-40	4
80-95	2
Total	10

*Some respondents are divisions or subsidiaries; corporate-wide figures may differ from those reported.

received funds were often experienced. Some also indicated that several significant R&D projects were delayed and jeopardized because of flucuations in outside funding.

Internal Funding Arrangements

In order to understand the process through which internally funded R&D budgets are determined, we asked the industry representatives several questions regarding internal funding arrangements for R&D. The responses to these questions are summarized in Table 4.4.

Ten of the twelve respondents indicated that separate budgets for research and development exist within their firms or divisions. Several of these indicated that separate budgets are provided for different research types; one representative indicated the existence of three separate research budgets within the product division alone. Generally, the separate research budgets were divided by different research types although all activities do not always fit exclusively into a single type. Departments engaging in activities most closely related to basic research were most likely to have their own budgets. These separate budgets are significant in that they suggest the possibility that different procedures and criteria are applied to allocate funds to activities related to basic research. This issue is discussed in more detail later in this section. (See the discussion of Table 4.6, beginning on page 71.)

As is indicated in Table 4.4, five of the respondents represented subsidiaries or divisions belonging to firms that

Table 4.4

INTERNAL R&D FUNDING ARRANGEMENTS

Funding Arrangement	Number of Responses (out of 12)
Separate Budgets for Research and Development	10 out of 12
Separate Budgets for Basic Research	4 out of 12
Existence of Parent Corporate Research Laboratories	5 out of 12
Direct Funding of Specific Projects at Corporate Labs by Product Divisions	4 out of 12

financed corporate-wide research laboratories. In four of these cases, product subsidiaries or divisions sometimes directly financed basic research projects conducted at these corporate-wide laboratories. However, the product divisions' main involvement was not direct funding but attempting to influence the direction of activities at corporate labs to their own needs.

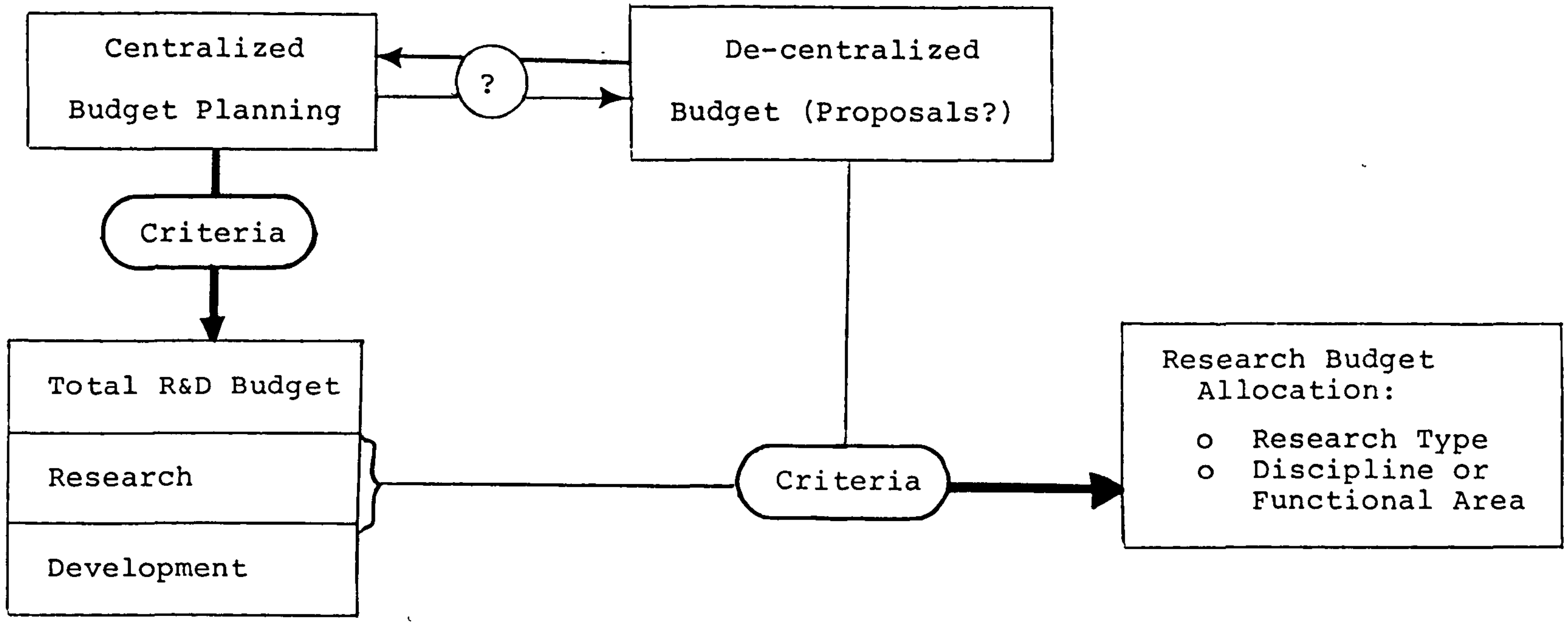
R&D Budget Allocation Procedures

Having established the relative size of the internally funded research budget, the discussions turned to how decisions are made by the company with regard to the budget itself and to individual projects. Ultimately, budgets for private sector firms are determined by adding detailed budget lines from the bottom up. Nonetheless, the process through which the size and shape of the budget is determined is significant. Procedures designed to determine budget allocations, for example, can place constraints on R&D expenditures in terms of budget ceilings. In addition, the criteria employed to allocate funds among research activities directly influence activities in laboratories.

Each of the representatives was asked a series of questions designed to describe the internal budget allocation process for their respective firms, subsidiaries, or divisions. The schematic in Figure 4.3 was presented to each interview subject. First, we explained that we were interested in the degree to which the budget planning process was centralized or decentralized, and the roles that interactions between

Figure 4.3

RESEARCH BUDGET ALLOCATION (INTERNALLY FUNDED)



decentralized departments or offices and central corporate offices played in forming R&D budgets. Next, we asked representatives to identify the criteria that are employed to determine the size of the total R&D budget. Finally, interview subjects were asked to describe the process and criteria used to allocate the total R&D budget among different research types, and to the extent possible, among different disciplines or functional areas of research.

The process through which the internal R&D budget is allocated appears to be similar across private sector firms. In particular, each of the representatives indicated that the corporate strategic plan is used to determine the size and shape of internally funded R&D budgets. Although the details of the strategic plan and the processes through which it is formed vary across firms, no significant differences were described.

There are several features of corporate strategic plans that are especially relevant to the present discussion. These include:

- The length of the plan.
- The level of plan detail.
- The origin of the strategic plan.
- Interaction with technical personnel.
- Product concepts and R&D activities.
- Criteria for budget allocation among research types.
- Product concepts and R&D activities.

Each of these features of strategic plans is discussed below in detail.

Length Of Strategic Plans

As Table 4.5 indicates, six of the respondents indicated that their subsidiaries or divisions relied on a five-year corporate strategic plan. Five of the other representatives described strategic plans varying between 10 and 15 years. In general, strategic plans are more clearly focused when the plan year is closer to the current year. One representative of a firm having a ten year plan, for example, indicated that any plans extending beyond three years were somewhat speculative and that any major current activities would have been planned three years in the past. Another firm with a ten year plan also developed a shorter, more detailed, five year plan. The degree to which long-term plans are focused also appears to depend on the technologies. Engine producers, for example, appear to have more detailed future plans, owing to numerous well-defined testing phases required to bring new technologies and engines to the market. Those firms receiving substantial external R&D funding from the military also appear to have the longest strategic plans. This is probably due to relative market stability of military funding.

All of the corporate strategic plans described to us were reviewed at least annually. Several of the representatives indicated that their strategic plans were reviewed during the course of the year as a standard practice. In addition, fairly

Table 4.5

LENGTH OF STRATEGIC PLANS

Length of Strategic Plan (Years)	Number of Responses (out of 12)
5	6
10-15	5
Total	11

radical changes in strategic plans may occur if the firm makes a decision to terminate or speed-up a major project.

Although the evidence is only suggestive, the duration of the corporate strategic plans provides information on the inclination or willingness of private sector firms to engage in long-term research projects. The prevalence of five and ten-year plans suggests that firms, in general, are unwilling to commit substantial funds to research projects expected to last beyond the five or ten years. As we explain later in this section, all major expenditures undertaken by the firm must be justified in terms of the strategic plan. Thus, it is clear that the length of this plan does place constraints on the type of research undertaken.

Some caution, however, should be taken regarding the interpretation offered immediately above. This does not mean, for example, that research projects extending beyond the length of the strategic plan are never undertaken. First, some research projects eventually extend beyond the period for which they were originally projected. Second, a strategic plan may, in some cases, call for a particular research project to be initiated in the future, recognizing that the completion of the project will likely extend beyond the duration of the strategic plan. These projects, however, are not likely to represent a significant portion of the firm's internally funded research. This point is discussed in greater detail below.

The Level Of Plan Detail

The final versions of corporate strategic plans define corporate activities, in varying degrees of detail, over the duration of the plans. Detailed, current year budgets are usually developed for consistency with strategic plans. However, the final versions of plans are generally the products of multi-phased interactions between corporate level planners and personnel representing various functional areas (e.g., marketing, manufacturing, engineering, and finance) of divisions or departments associated with specific product lines. The levels of detail contained in the original draft of the strategic plans are also of interest for this study because these drafts usually define the marketing goals of the corporation.

A few of the representatives of subsidiaries or divisions of large multiproduct corporations indicated that the first stage in the development of the strategic plan was the construction of an "external world environment" statement or analysis that was prepared by corporate level planners. Generally, the external environment statement provides projections of scenarios exogenous to the individual firm. For example, major political or international events (e.g., the likelihood of a war, or significant changes in trade relationships) are projected in the external world environment statement. Important demographic trends are also noted, and the possibility of significant new markets opening, or old markets declining, are described.

The world environment statement, by itself, does not typically identify specific products or detailed strategies by which the corporation might capitalize on external factors. Rather, the likelihood of significant events are described, and individual subsidiaries, divisions, or product lines are expected to develop detailed plans that recognize the major events predicted in the environment statement. It should be noted that those subsidiaries or divisions receiving external environment statements proceeded at the next stage of the development of a corporate strategic plan in a fashion nearly identical to those firms that worked without such a statement.

At a minimum, most first drafts of strategic plans define what several representatives referred to as "product concepts". Product concepts describe or define general market slots for specific products that will be produced in the future by the company, and some contain detailed performance specifications. More detailed specifications for individual products are generally defined through subsequent iterations on the strategic plan if they are not described in the original draft.

Some original drafts of the corporate strategic plans contain very detailed performance specifications of products including the number of passengers, aircraft range, aircraft speed, and fuel consumption. Similarly, many of the original drafts of strategic plans provide detailed specifications of

economic parameters such as product price, market share projections, cost projections, and product timing (i.e., when the product is to be introduced to the market).

The level of detail contained in the original draft of the strategic plan is significant in determining the size and shape of the internally funded R&D budget. As we explain later in this section, virtually all significant R&D activities undertaken by the firm must be justified in terms of the corporate strategic plan. (See discussion beginning on page 61.)

Origin Of Strategic Plans

Each of the interviewed representatives was asked to identify the individual or group of individuals responsible for writing the first draft of the corporate strategic plan. With one exception, all of the representatives indicated that committees or "councils" prepare first drafts. Generally, several functional areas within the firm are represented on these committees. One representative, for example, indicated that the planning committee included personnel from engineering, manufacturing, finance, marketing, and product support.

Despite the somewhat varied representation on these committees, marketing personnel are included as members in virtually all cases. In particular, marketing personnel appear to provide input to define product concepts in terms of market slots in which future production will be directed. As was noted earlier, such initial input is significant to the extent that virtually all R&D activities are justified in terms of corporate

strategic plans. That is to say, the product concepts, which are defined in terms of markets, dictate to a large extent, the size and shape of internally funded R&D budgets.

Interaction With Technical Personnel

An important policy issue is the extent to which inputs from technical personnel shape the R&D activities of private sector firms. Some of the committees charged with the responsibility of drafting original versions of corporate strategic plans include technical personnel in their membership. The definition of the product concepts appears to be the dominant feature of original drafts of strategic plans.

Technical personnel serve two important roles in the formation of the final corporate strategic plan. First, they are generally asked to review and respond to the technical feasibility of the various drafts of the strategic plan, including the first draft.[2] Second, technical personnel are generally required to develop detailed R&D plans, including budget estimates, that are consistent with the goals of the corporate strategic plan.

Typically, the technical feasibility of corporate strategic plans is defined in terms of several key parameters. The most important of these include:

- the likelihood of technical success;

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[2] One representative did indicate that technical people played only a very minor role, at any stage, in shaping the corporate strategic plan.

- the feasibility of meeting the schedule defined in the strategic plan;
- the likelihood of completing projects within budgets.

Most of the respondents indicated that a final version of the corporate strategic plan is developed after several iterations between the committee responsible for the original draft, and representatives of various functional areas of the firm, including technical personnel. All functional areas of the firm were then responsible for developing detailed plans of their own--including detailed budget estimates--that are consistent with or can be "justified" in terms of the final version of the strategic plan.

Criteria For Budget Allocation Among Research Types

The representatives of the various firms, subsidiaries, and divisions were asked to describe the criteria used by their respective firms for allocating the annual budget among different research types--i.e., basic research, applied research, and technology demonstration. Based on the responses obtained in the interviews, it appears that most research budgets are derived principally from the strategic plan; that is, most planned research activities are designed for consistency with product concepts defined in strategic plans.

Basic Research--Four of the respondents indicated that a small portion of their total internally funded research budgets do not have to be justified in terms of the strategic plan. These "unjustified" activities, in most cases, can be classified

essentially as basic research. It is also interesting to note that these unjustified research activities, in each case, are funded out of distinct and separate budgets.

Generally, however, the unjustified portions of research activities are small relative to total research budgets. One representative, for example, indicated that a special research fund, which represents approximately 10 to 12 percent of the total internally funded research budget, was set aside for a research department whose activities were not predefined by the corporate strategic plan. However, the administrator of the fund was present at the interview, and indicated that he used the budget to attempt to solve relatively short-term special problems that surfaced during the development cycle.

Another representative indicated that a special research fund independent of the strategic plan was established in his firm, but it represented a maximum of only two percent of total internally funded research. Two other respondents indicated that their firms typically set aside between five and ten percent of the internal research budget, unjustified in terms of the corporate strategic plans.

Those representatives who indicated the existence of independent research budgets were asked what criteria their firms use to establish the size of such a budget. In most cases, the size of the budget appears to be determined largely by historical

precedent: that is, limited funds are allocated for research not committed directly to projects or products related to the product development cycle.

Some respondents indicated that the size of the uncommitted budget is sensitive to corporate cash flow positions. (For example, one representative indicated that while the firm would incur debt to finance development costs, it would never incur debt to finance research. Another representative indicated that research funds or budgets are sensitive to the product cycle since scientific personnel are moved from research laboratories to development facilities during periods of heavy development in an effort to allocate resources directly to problems that may surface relative to projects close to commercialization.

The discovery that the uncommitted basic research budgets in our sample are determined mostly by historical precedent suggests that private sector firms performing basic research view it as a quasi-fixed input to the production process. That is to say, some (albeit small) amount of uncommitted basic research, when combined with other resources employed by the firm such as those directed to technology demonstration, product development, manufacturing, and marketing, are useful in delivering final products in the marketplace. Mansfield (1984) came to a similar conclusion in a recent study of the effects of R&D tax credits on

private sector R&D expenditures.[3] His interpretation is supported by Nadiri and Schanherman (1981) who find extremely low price elasticity of demand for R&D.[4] The price elasticity of R&D measures the percent change (increase) in private sector R&D expenditures associated with a one percent change (decrease) in the cost of research. A low R&D price elasticity indicates that, at least over the relevant range, the level of research expenditures by the firm is relatively fixed in that it is insensitive to changes in R&D costs. The use of variable inputs (such as those used in manufacturing) is more likely to be sensitive to changes in the price of inputs.

The interview subjects were asked to indicate why their respective firms provided funds for basic research activities independent of corporate strategic plans. Three justifications were mentioned. First, there is a small probability that personnel engaged in basic research will produce an important technical success which will result in commercial success. Second, technical personnel engaged in basic research are some-

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[3] Mansfield, Edwin. Public Policy Towards Industrial Innovation: An International Study of Direct Tax Incentives for R&D. Paper presented at the 7th Annual Colloquium on Productivity and Technology, Harvard Business School, 1984.

[4] Naridi, I. and M. Schanherman. "The Structure of Productivity, Technological Change, and the Rate of Growth of Total Factor Productivity in the Bell System," IN T. Cowing and R. Stevenson (eds.) Productivity Measurement in Regulated Industries. New York: Academic Press, 1981.

times useful for assimilating and interpreting basic research available through the literature and other sources outside the firm. Third, periodically rotating technical personnel into basic research can improve morale and technical competence.

Applied Research--All respondents indicated that virtually all applied research must be justified in terms of strategic plans. As is explained later, most applied research is directed to the eventual development of technologies embodied in the product concepts identified as part of the corporate strategy. Applied research projects are sometimes relevant to several product concepts which constitute a product line. Ultimately, the size of the budget allocated to applied research depends on the technologies embodied in product concepts. The relationship between applied research and product concepts is discussed in more detail later in this section.

Technology Demonstrations--Technology demonstrations are virtually always directly relevant to strategic plans. In most cases, the firm has a rather clear picture of the product to which the new technology will apply. Thus, the product concepts are, in relative terms, clearly defined at this stage. Often, technology demonstration is conducted only if technical risk cannot be reduced to acceptable levels at the applied research stage. Technology demonstration is also more likely to be focused narrowly to one or a few products than applied research.

Finally, it should be noted that several respondents indicated that their firms required even basic research to be

justified in terms of strategic plans. Although it is difficult to focus basic research to specific product concepts, the companies claimed that it was possible to relate it to potential downstream technologies that might be developed as a result of further applied research and technology demonstration.

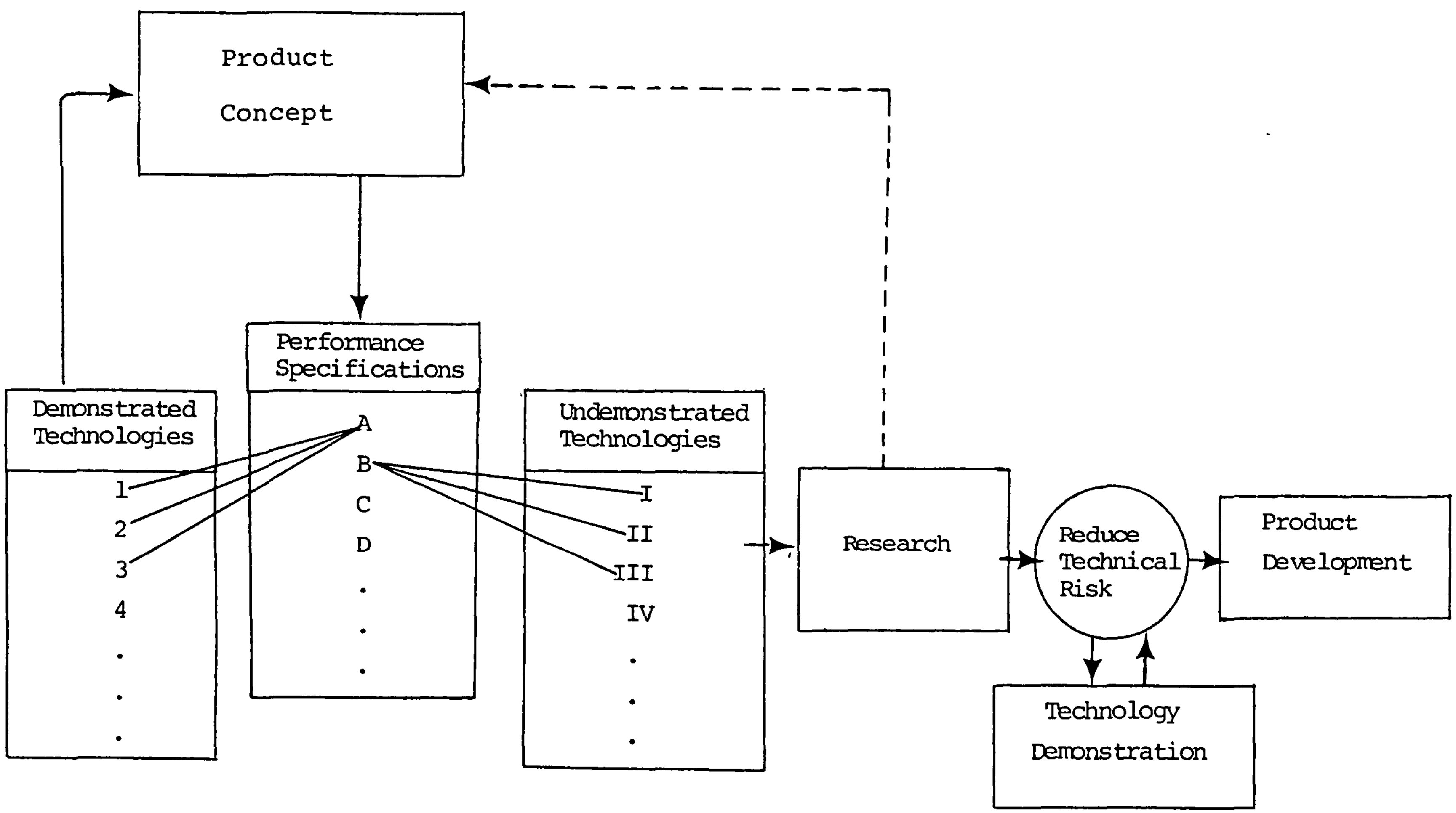
Conclusion: Strategic Plans Largely Determine the Allocation of Resources Among Research Activities

The preceeding discussion suggests that virtually all R&D activities conducted by private sector firms are justified in terms of corporate strategic plans. Earlier, we noted the role that the product concept played in the shaping of strategic plans. The respondents provided relatively detailed information regarding the interplay between the formation of the product concept and the definition of the scope of internally funded R&D activities. The discussion below describes the critical role that the product concept plays in shaping R&D activities of private sector firms. It is important to note, however, that product concepts themselves are dynamic, and become more detailed, the closer they come to the development stage.

The interplay between the product concept and R&D activities is illustrated in the schematic displayed in Figure 4.4. As was explained earlier, the product concept is defined in terms of a set of performance specifications, say, for a particular aircraft. These performance specifications become more clearly defined, the closer the product is to development.

Figure 4.4

PRODUCT CONCEPTS AND R&D ACTIVITIES



In turn, the performance specifications depend on a set of technologies, some of which have already been demonstrated and some which have not yet been proven. Virtually all research activities of private sector firms are directed to reducing the technical risk associated with these undemonstrated technologies that are embedded in product concepts. As we explained earlier, only some (but not all) basic research is not focused directly to technologies planned for future products.

Two arrows flow to the product concept box in Figure 4.4. First, product concepts are defined initially in terms of available (i.e., demonstrated) technologies, and, to some extent, those technologies being developed through research activities. Second, the product concept evolves as the firm's research activities define the feasible set of technologies, and hence, the feasible set of performance specifications. Those performance specifications relying on technologies that cannot be demonstrated are eliminated, and feasible alternatives are substituted.

The role that technology demonstration plays in the process warrants further comment. In most cases, demonstration activities are undertaken only after a product concept is well-defined. Technology demonstration is often conducted only if technical risk cannot be reduced to an acceptable level through other research activities. However, because of substantial

costs, it appears that firms are often unwilling to undertake technology demonstration if significant technical risks are still present.

To a lesser extent, these same comments apply to applied research. One fundamental objective of research is to reduce the risk associated with a potential technology. At the same time, however, applied research activities at private sector firms are dictated by the as yet undemonstrated technologies required to satisfy the performance specifications of product concepts. The product concepts defined in strategic plans, in many cases, embody relatively low technical risk, and accordingly, the applied research likewise tends to hold low or moderate technical risk.

This finding is consistent with the discovery that relatively few resources are devoted to funding basic research, and that relatively few funds are devoted to financing unjustified research (in terms of strategic plans). This discovery is also consistent with an earlier observation by Mansfield (1971). Specifically, Mansfield finds that most internally funded research projects carry relatively low technical risk, and that in addition, the willingness of private sector firms to accept technical risk is less than their willingness to accept market risk.[5]

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[5] Mansfield, Edwin, John Rapoport, Jerome Schee, Samuel Wagner, Michael Hamburger, Research and Innovation in the Modern Corporation. New York: W. W. Norton, 1971.

This behavior is certainly understandable. Since research activities precede the introduction of a new product into the market, firms are effectively accepting both technical and market risks in funding research. Once the firm reaches the development stage of the cycle, however, most of the technical risks embodied in the product have already been reduced or eliminated. At this stage, market risk is the major problem facing the firm.

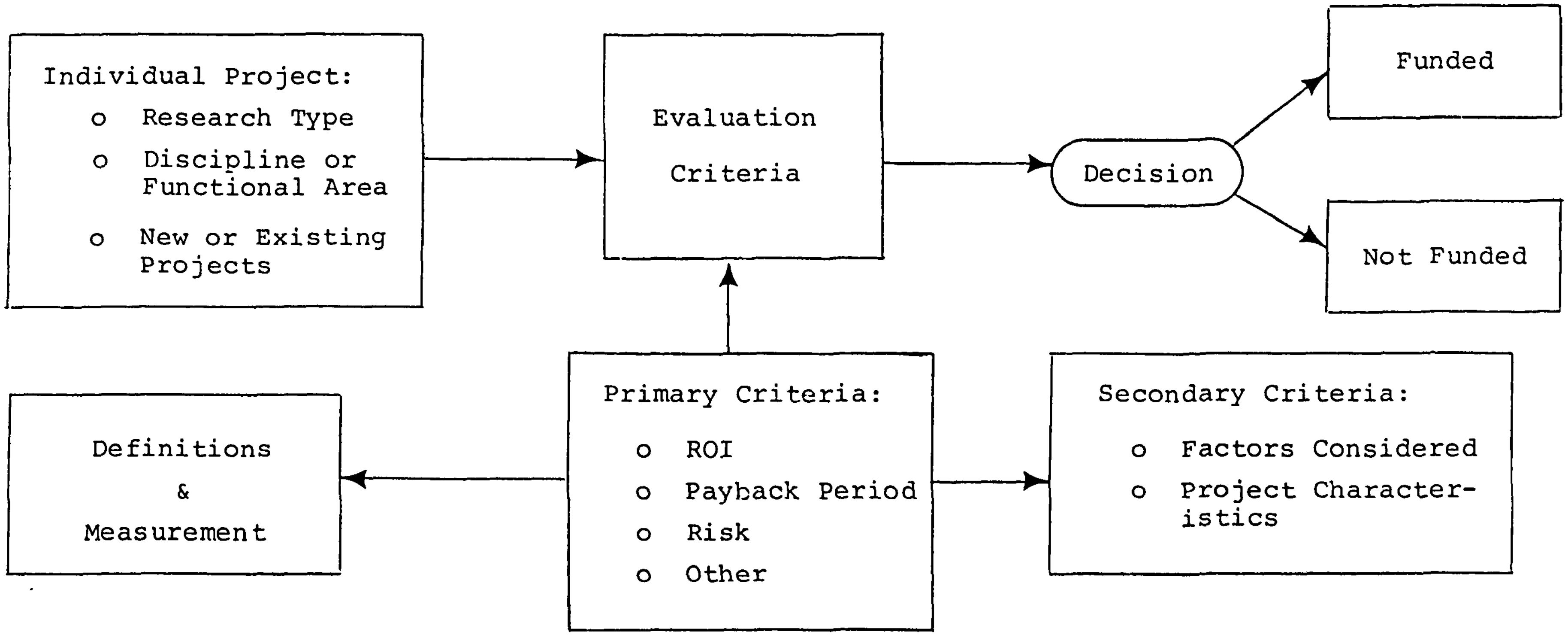
Evaluation of Individual R&D Projects: Methods and Criteria

The primary objective of this fourth and final phase of the interview was to discover how private sector firms make decisions on individual R&D projects and to determine what characteristics of individual projects lead to acceptance or rejection. In order to focus the discussion, interview subjects were shown the schematic illustrated in Figure 4.5.

We explained that our primary interest was in identifying the criteria that were used to evaluate individual projects, and to determine if different criteria or methods of evaluation were used across research types, disciplines or functional areas, and new existing projects. Three primary economic criteria upon which such decisions are based were suggested: return on investment (ROI), payback period, and risk.

Figure 4.5

REVIEW CRITERIA (INTERNALLY FUNDED)



We further explained that there may be other criteria used by the firm and asked that such criteria be identified. Finally, the interview subjects were asked to describe the definitions of the criteria that were employed and the techniques that were used to measure the key parameters necessary for the evaluations. In addition, the representatives were asked to identify any secondary criteria that might be relevant to their evaluation of individual R&D projects.

All of the respondents indicated that they employed some or all of the primary criteria identified in Figure 4.5. As the following discussion suggests, however, <u>these primary criteria are generally applied to the evaluation of specific products (including development and some demonstration activities), but not directly to research projects. Accordingly, research projects are formally evaluated only to the extent that they received implicit evaluation within the context of product evaluations.</u>

<u>Return On Investment Criteria</u>

All of the respondents indicated that their respective firms, subsidiaries, or divisions employed the return on investment criteria. In all cases, however, this criteria was applied to specific products, and never directly to specific research projects. As we suggested above, research projects are evaluated implicitly by this criteria, to the extent that they are included in the product evaluation process.

The basic method for evaluating ROI that was described to us appears to be standard discounted cash flow (DCF) analysis. The following three classes of parameters are necessary to implement this method:

- o Projected revenues associated with the product (based on estimated product price and market share).
- o Costs--both nonrecurring (i.e., fixed costs including research and development costs) plus recurring or variable costs (e.g., manufacturing and selling costs).
- o The timing of costs and revenues.

In addition, of course, an appropriate discount rate which reflects the firm's marginal cost of capital is necessary to implement the DCF method.

If research projects are to be implicitly evaluated within the ROI product evaluation, the benefits and costs associated with specific research projects must be included in the revenue and cost estimates. Theoretically at least, the appropriable benefits of research projects necessary to make feasible the performance specifications embodied in the product concept should be included implicitly in the projected revenues. That is to say, both the price of the product and the estimated market share (i.e., quantity sold) are a function of the attributes of the product which have evolved from the product concept. Such benefits should be included in revenue projections for each of the several products for which an individual research

project might be applicable. Research costs are nonrecurring and should be treated as such in the ROI analyses.

Unfortunately, the preceeding prescription for evaluating projects in terms of ROI is difficult to implement for research projects. This is especially true for basic research; none of the respondents indicated that basic research projects are evaluated in terms of ROI, either explicitly or even implicitly within the context of product evaluations. There are a number of reasons for this.

First, it is difficult to project the downstream revenues associated with basic research projects. The objective of basic research is to obtain an understanding of a phenomenon. Even after this is accomplished, there is no guarantee that any commercial application will be possible. On the other hand, a range of applications may be possible, but it is difficult to identify the specific products to which they may be relevant, and probably even more difficult to estimate product prices and market shares. These problems are compounded in view of the fact that most technologies make only marginal improvements in the value of the product, but many potential improvements must be evaluated simultaneously.

Second, the costs associated with the applied research, demonstration, development, manufacturing and other activities that follow basic research are difficult to forecast with reasonable certainty. In short, it is difficult for the private

sector firm to assess the downstream appropriable benefits and costs associated with specific basic research projects.

It also appears that private sector firms face difficulty in formally assessing the downstream appropriable benefits and costs associated with applied research and demonstration projects. Only four of the respondents indicated that their respective firms, subsidiaries, or divisions include applied research projects in ROI evaluations. Six of the twelve respondents indicated that technology demonstrations are evaluated in terms of ROI. Again, in all cases, projects are evaluated within the context of product evaluations. In general, respondents stressed that their firms were generally unwilling to commit any substantial funds to projects unless a thorough economic evaluation of such projects was possible. Such an evaluation requires that the benefits and costs associated with the specific project can be evaluated. As we noted earlier, only those benefits associated with a research project that are appropriable are properly considered in any private sector economic evaluation.

All actual benefits associated with a specific research project may not be appropriable by the sponsoring firm, since some of the benefits flow to other industries and to competitors within the firm's own industry. In addition to these unappropriable benefits, we must include those benefits that might otherwise accrue to the individual firm, but which are not

perceived. In short, it is only those appropriable benefits that are perceived that matter to the private firm.

The practices employed by private sector firms to assess individual R&D projects shed some light on the degree to which they are able to "perceive" or measure appropriable benefits associated with different R&D types. Relative to other R&D types, for example, the benefits associated with specific basic research projects are most difficult to assess because they are never evaluated through ROI analysis. At the other extreme, the respondents indicated that development projects are almost always evaluated in terms of ROI; thus, the appropriable benefits associated with development are the easiest to measure or assess.

It is important to recognize that private sector firms also attempt to evaluate the benefits associated with specific R&D products in terms of relevance to strategic plans. This evaluation process does not necessarily require numerical estimates of appropriable benefits, but nonetheless, is made with a view of market conditions since product concepts, a key component of the strategic plans, are defined at least in terms of market niches. In turn, market niches characterize, at least subjectively, the expected appropriable benefits. Accordingly, the degree to which R&D types are "justified" in terms of strategic plans also reveals the ability of firms to assess appropriable benefits.

Table 4.6 presents a ranking of the ability of private sector firms to assess benefits of different R&D types in terms

Table 4.6

ASSESSMENT OF R&D

R&D Type	Assessment Technique	
	Strategic Plan	ROI Analysis
Basic Research	Sometimes	Never
Applied Research	Usually	Usually Not
Technology Demonstration	Always	Sometimes
Development	Always	Almost Always

of relevance to strategic plans and ROI analysis. Basic research is the most difficult to assess by either assessment technique: it is justified in terms of the strategic plans "sometimes," but is "never" evaluated in terms of ROI. Applied research is "usually" justified by strategic plans, but is "usually not" evaluated in terms of ROI. Technology demonstration is virtually "always" justified by strategic plans, but only "sometimes" included in ROI evaluations. Finally, development is virtually "always" justified by strategic plans and "almost always" included in ROI evaluations.

Although these joint rankings provide information on the ability of private sector firms to assess appropriable benefits, it should be recognized that the dominant assessment technique is ROI analysis. This technique is dominant in the sense that private sector firms do not generally commit substantial resources to a project unless the application to a specific product or product line can be identified, and the product itself has undergone a rigorous assessment.

Since many of the respondents indicated that basic and much applied research--and sometimes even technology demonstration--is not evaluated either implicitly or explicitly within the context of formal product evaluations, we asked them to describe alternative criteria that their firms use in making selections among alternative potential research projects. The criteria identified were very similar across all respondents. These criteria include:

- Promise of technical success.
- Relevance to product lines.
- Relevance to the strategic plan.

The promise of technical success was based primarily on the recent history of the project as well as the past success rates for the personnel associated with the project.

Identifying where Technical and Economic Criteria Dominate Decisionmaking

The preceding discussion suggests that the process of R&D decisionmaking can be segregated into areas in which economic criteria and technical criteria predominate.

- Economic criteria dominate strategic plans which define product concepts and performance characteristics. Decisions concerning some technology demonstrations and virtually all development projects are also dominated by economic criteria.
- Technical criteria guide the selection of specific basic research projects, many applied research projects, and to some degree, even technology demonstration. Firms use technical criteria to guide technology and research projects that are designed to meet the "needs" defined in product concepts.

The product concept is evaluated using economic criteria (i.e., ROI), but research and technology projects are not generally evaluated directly using economic criteria. This, to a large extent, defines the point in the R&D decisionmaking process

where firms can assess the appropriable benefits associated with a given technology. As was noted above, firms do not generally commit significant funds until appropriable benefits are perceivable.

The Payback Period

The interview subjects were asked several questions regarding the payback period requirements for different R&D types. Specifically, we attempted to obtain the following information:

- o The maximum acceptable payback period for different R&T types.
- o The maximum acceptable time period between project start-ups and commercialization for different R&T types.
- o The maximum acceptable time period between project start-ups and project completions for different R&T types.

All respondents agreed that, other things being the same, projects with shorter payback periods, times to commercialization, and times to completion are preferred. None, however, indicated that any absolute or maximum threshold criteria are employed by their respective firms, subsidiaries, or divisions. In practice, actual time periods vary substantially and depend primarily on differences in technologies, product life cycles and markets.

It is notable that technology demonstrations conducted by private sector firms usually are completed shortly before development, and usually if a specific application is expected. In addition, it appears that private sector firms do not often engage in long-term basic research projects; that is, the time between project start-up and expected project completion is usually relatively short, and often shorter than that for applied research. It should be stressed, however, that exceptions to both of these observations were noted by the respondents.

The Evaluation Of Risk

Some type of risk analysis is conducted by all of the firms represented in the interviews. In general, both the overall technical risk embodied in the product concept, and the technical risk associated with specific technologies are evaluated. The degree to which formal risk analyses are conducted, however, varies substantially across the representative firms. Specifically, practices vary from formal numerical risk evaluation to less formal subjective evaluations.

Typically, risk is measured as a likelihood of an adverse event occurring. Some firms attempt to estimate the probability of a failure numerically; others attempt only qualitative assessments (e.g., high, moderate, low). Finally, other firms make no attempt at either quantitative or qualitative estimates of risk, but considered it subjectively.

Risk is generally considered for the following specific factors:

- o Technical feasibility--i.e., will the technology operate as expected when embodied in a product concept?
- o Budget risk--can the necessary result be obtained within the research budget?
- o Schedule risk--can the project be completed within the schedule necessary for a planned product commercialization?

Although some respondents indicated that their firms would never undertake substantial development costs before a rigorous assessment of the risks embodied in the product concept, risk analysis for specific products is often made after a decision to carry forth with the project has been made. First, a return on investment analysis of a new or improved product is conducted. This analysis generally precedes the risk evaluation, sometimes by a period of a year or more. Risk analysis is then conducted after detailed technical plans for the new project are completed. Accordingly, risk is often not used as an evaluation tool per se. Rather, it is used to identify those areas that carry a high degree of technical risk so that technological options can be developed. In short, risk analysis often tells the firm that more analysis of a specific technological attribute of a product may be required, and that technological options for risky attributes should be developed.

Although exceptions can be noted, some observations on the willingness of private sector firms to accept technical risk in research projects are noteworthy. First, in virtually all

firms, research projects must be justified in terms of product concepts described in strategic plans which, in turn, limits the riskiness of research activities since the product concepts themselves are usually defined in terms of demonstrated technologies or technologies close to the demonstration stage.

Second, although basic research projects are often unjustified in terms of product concepts, firms tend to minimize risk by engaging in a large number of small basic research projects. One representative, for example, indicated that he currently was responsible for directing approximately 90 different research projects even though his total budget was relatively small. Thus, where research projects are risky--such as is usually the case with basic research--the private firm tends to be a self-insurer by accumulating a diversified portfolio of relatively small inexpensive projects. Given these two observations, it is unlikely that many private sector firms would be willing to undertake the substantial technical risk that is associated with many of the large projects undertaken by NASA.

Third, firms tend to be risk averse in conducting costly technology demonstration projects. The level of technical risk is usually low, and, as noted previously, a specific application is usually identified. Some respondents indicated that their firms were reluctant to conduct technology experiments that might apply to a range of products, for fear that the results of the experiment might not be valid across aircraft types. Representatives of some firms stated that they sometimes conducted large,

risky demonstrations that might be relevant to military projects; however, the potential for receiving IR&D credit mitigates financial risk to the firm in these cases.

In order to determine the degree to which private sector firms are willing to accept technical risk, interview subjects were asked about success rates for past projects. None indicated that such data were available, partly because of the difficulty in defining "technical success." Most respondents stated, however, that success rates vary over time and across technologies.[6]

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[6] National Science Foundation. Basic Research, Applied Research, and Development in Industry, 1962. Published 1965.

SECTION V. POLICY IMPLICATIONS

Introduction

In the last section, specific findings were reported with regard to the motivations of commercial aeronautics firms to internally finance research and development projects. Based on these results, this section presents the policy implications, and specifically addresses the question:

- What types of productive research and technology programs are private sector firms likely to underinvest in?

It is in these productive programs that NASA's involvement is most needed.

Any evaluation of potential NASA projects must begin with the technical merits of the proposed activity. These matters are currently considered in NASA's decisionmaking process; projects of high technical merit should ultimately lead to technological advances which create social benefits. This does not mean that it is NASA's role to bring these innovations to the marketplace, but only to facilitate some productive technological activities which the private sector can then commercialize and on which the Department of Defense can also capitalize where this is feasible.

These project selection criteria are similar to those considered in the private sector. Where the private and public

sectors diverge is in their willingness to accept certain project-specific characteristics relating to:

- Problems of appropriability,
- Specific economic characteristics.

Based on our discussions with key aerospace firms and previous research, there are certain appropriability and economic characteristics of programs which the private sector will avoid. When these projects are likely to be productive--when they have technical merit and create social benefits--then they are properly considered as candidates for NASA sponsorship.

Defining The Characteristics Of Projects That Reduce Their Attractiveness To The Private Sector

The relevant characteristics have been segregated into two groups: those related to appropriability problems and those related to specific economic characteristics of certain projects which make them less attractive to the private sector. Below, we review each of these characteristics in turn and then provide conclusions about the likelihood of the private sector investing in projects with one or more of these characteristics.

Appropriability Problems

We have segregated the appropriability problem into two separate but related areas:

- Difficulties in assessing appropriable benefits of projects,

- Difficulties in capturing the benefits of research and development activities.

Each of these is discussed in turn below.

Assessing the Commercial Relevance of R&D Projects--Private firm investment decisionmaking, including that related to R&D, is based for the most part on the firm's strategic plan which in turn is a function of the availability of the commercial opportunities. Typically, a firm will assign virtually all of its limited internal R&D research resources to the products and product concepts defined in its strategic plan; also, the firm will be more likely to devote significant resources to a project if it can measure a rate of return on the investment. Basic research often cannot be related to the strategic plan and can never be evaluated directly in terms of ROI. As a result, basic research is done only by large, well diversified firms which look upon basic research as a fixed input to their multi-product production functions. Firms also have difficulty measuring the private benefits (ROI) of most applied research projects; but more resources can be devoted to applied research since its relevance to products and product concepts can be identified. In effect, the applied research is evaluated as a necessary input to achieve the ROI projected for a product or product concept.

Firms are able to devote significant resources to development programs because the ROI can be directly evaluated, and the relevance to the strategic plan is direct--i.e., the development project is usually one of the product or product

concepts in the plan. The same is often, although not always, the case for technology demonstration.

Insufficient Capturability of Benefits--There are at least three separate but related reasons why firms sometimes find it difficult to capture a sufficient amount of benefits to justify investments in certain types of R&D activities. First, there may be a large number of applications of a technology which together would justify continuing a project, but the firm's opportunity set does not include enough of them to produce sufficient benefits. Second, there may be difficulties in patenting R&D results which in turn reduces the likelihood that the firm will be able to protect its innovations for a sufficient period of time to reap sufficient benefits. Third, whether or not the results are patentable, if they are easily replicated (including avoiding a patent) then the firm is less likely to garner sufficient benefits to justify the investment.

Obviously, the degree to which these problems of capturability are important depends upon the technology and the markets involved. Problems of capturability can and do exist at each stage in the R&D process. The full benefits of basic research are almost by definition, not fully capturable by the firm. The results are unlikely to be patentable, and are likely to be widely applicable. Whether or not they are easily replicable may depend on the technology; new materials research may be harder to replicate than aerodynamics advances, for example. The ease of

replicability also depends on the amount and quality of information published concerning the advance. But, in general, one reason firms do very little basic research is the difficulty in capturing its full range of benefits.

At later stages in the R&D process, the capturability issue has a direct impact in the ROI calculations firms make when committing resources to technology demonstration and development projects. Here the effects are much more direct: if the capturability problem is severe enough, the private benefits of a project will be insufficient to cover costs, and no further internal funding will be forthcoming.

Other Economic Characteristics of Specific Projects

There are three relevant economic characteristics of specific projects which can have an effect on the firm's willingness to undertake certain R&D projects; they are: technical risks, long payback periods, and large size of project relative to the minimum efficient size of the firm. Each of these is discussed briefly below.

Technical Risk--The survey findings indicated that the willingness of firms to accept technical risks declined significantly as a project moves through the R&D process. One key objective of applied research and technology demonstration is to wring out most of the technical risk before development takes place. Even at the applied stage, because the technology is linked to product concepts on which the firm depends, heavy investment in high risk activities is unlikely.

Long Payback Period--The strategic plans of firms extend to between five and fifteen years, depending upon the technology involved. When devoting significant resources to a project however, firms expect earlier payback to be forthcoming. That is, in their return on investment analyses, firms will plan on relatively short payback periods for technology demonstration and development projects. Whether or not these early paybacks are forthcoming will depend upon the market, but few projects will be commercialized if their planned paybacks are excessive.

Large Size of Projects Relative to the Minimum Efficient Size Firm--In general, firms devote significant resources to projects only when they can access their benefits. Very large projects early in the R&D process are virtually unknown. The size of a project that a firm will be willing to undertake at any stage in the R&D process will depend upon the technology involved, and the size of the firm. But, firms show great reluctance to undertake large projects at the basic and applied stage in the R&D process.

Likelihood Of Private Firms Internally Funding R&D Activities

With the factors defined, our objective is to provide a framework which can be used to supplement current NASA decision-making. The approach is to utilize these characteristics of projects in order to determine those projects which firms are likely to shy away from. Not explicitly considered are the technical merits of any project or its ultimate value in the

marketplace. But obviously, the potential productivity of any R&D activity is relevant in both the private and public sectors. Here, the objective is to identify those projects which the private sector is unlikely to invest in; if those projects are productive, then they should be properly considered by NASA.

The results are summarized in Table 5.1, and each type of R&D activity is discussed below.

Basic Research

In the survey, very few firms performed basic research, and no firm devoted more than a few percent of its own R&D resources to this activity. This is the case primarily because basic research is most likely to be affected by all four of the characteristics listed in Table 5.1. In short, basic research is an activity which is most unrelated to commercial activities and is subject to high risks and long paybacks whose results are often unappropriable. Firms generally minimize these activities and the majority of firms do virtually no basic research. For this reason, it is generally accepted that basic research is problematical in the private sector and is therefore an appropriate public sector activity.

Nevertheless, it is interesting to note that some basic research is done in the private sector, mostly by large, well diversified firms. To be sure, these activities usually make up less than one percent of the firm's R&D budget and the firm's motives for performing basic research lie outside the normal investment decisionmaking channels. In fact, many firms have

Table 5.1

LIKELIHOOD OF A FIRM INTERNALLY FUNDING R&D PROJECTS WITH CERTAIN PERCEIVED CHARACTERISTICS

	Inability to Assess Commercial Applications	High Technical Risk	Long Payback Period	Large Size of Project Relative to Size of Firm
Basic Research	Varies*	Varies*	Varies*	Very Low
Applied Research	Low	Low	Varies	Very Low
Technology Demonstration	Very Low	Very Low	Low	Varies
Development	Not Applicable	Very Low	Low	Varies

* Very little basic research is privately funded because the likelihood is high that firms will be unable to assess commercial applications and will face high technical risk and long payback periods. All other things equal, a firm is less likely to fund a basic research project than any other type of R&D activity.

separate budgets for basic research and the criteria used to allocate those budgets are different from any other investment criteria utilized by the firm. But, it appears that the possibility of appropriating the benefits of the research are higher in large, well diversified firms because of the greater number of products over which this activity can be spread. Furthermore, there are subsidiary benefits including raising morale and having greater technical competence available to the firm.

In general, the likelihood of a particular basic research project being funded in the private sector is relatively low, and this is especially true of larger projects.

Applied Research

The single most important characteristic with regard to applied research is that private firms are only likely to invest in it if its commercial applications can be assessed in the firm's strategic plan. This means, that in virtually every case, applied research must be tied to specific product or group of product concepts. Because of this linkage to product concepts and the firm's immediate future commercial plans, it is also unlikely that the private sector will be willing to undertake high technical risk in applied research projects. Furthermore, firms are very unlikely to devote significant resources to a single applied research project because large resource commitments in the R&D process are reserved for technology demonstrations and development which are much closer to commercialization.

Obviously, the interaction of these factors plays a significant role in determining whether the firm is likely to invest in a particular project. For example, some firms may be willing to tolerate a small applied research project with relatively high risk and a long payback that may extend for as many as fifteen years. But it is very unlikely that it would entertain such a project if it were large and/or if the commercial applications were not well defined. In sum, it is the interaction of the characteristics in Table 5.1 which is likely to determine whether or not a firm will invest in an applied research project.

Technology Demonstration

Many firms attempt to avoid this stage in the R&D process. Indeed, many firms had no regular budget item for technology demonstrations. However, in many cases, and especially with regard to propulsion technology, it is necessary to utilize technology demonstrations in order to reduce technical risks before development and commercialization of a new product.

Relative to applied and basic research done in a laboratory, technology demonstrations are expensive. For this reason, many firms have difficulty distinguishing between demonstration and development activities because they are so tightly linked to a specific product. In fact, in some cases, technology demonstration models become prototypes utilized in development activities. Therefore, it is very unlikely that a firm would fund a technology demonstration internally unless it knew its

direct commercial relevance. In fact, many firms are able to apply return on investment criteria to technology demonstration investments. In addition, most of the technical risks in these privately funded activities have been wrung out in the laboratory, although the degree will depend upon the technology involved. But, technology demonstration is not a high risk technical activity or at least it is not planned to be. It is unlikely that a firm would fund a technology demonstration of a radically new technology unless both the costs and likelihood of success could be predicted with high accuracy. Because of its nearness to commercialization, the planned payback period is also likely to be short.

In general, then, any technology demonstrations subject to high technical risks, long payback and/or unclear commercial relevance are unlikely to be undertaken in the private sector. For example, radically new technologies--e.g., structural ceramics for turbine engines--seem to fall into this category.

Development

A development program is the final and most expensive stage in the R&D process; it overlaps into the initial commercialization of a new product. By definition then, firms are able to assess the commercial applicability of the technologies involved in these programs.

Firms producing commercial aeronautics products never undertake development without planning to wring out most of the technical risk of a project either in the lab or in technology

demonstration projects. The commercial aircraft market will not pay for technologies which are unproven or incomplete and often it will not wait for problems to be overcome.

Much has been made of the long payback cycles for many aeronautics projects. However, firms seldom plan to develop products with extremely long payback periods; it sometimes happens, however, that the market does not develop as fast as was forecast in the firm's strategic plans. Acceptable paybacks are directly related to the duration of product life cycles. While the paybacks in aeronautics projects on average may exceed those typical in the electronics industry, they are consistent with the average life cycle of these products. Firms are therefore very unlikely to invest in development where the planned payback extends beyond say ten years; the opportunity cost of the capital and the interest charges for projects extending beyond this time period are far too high.

Aeronautics firms are distinguished by their willingness to accept very large size development projects. But these projects are justified by standard return on investment criteria which include market risk and payback considerations. The willingness of firms to accept large projects given an acceptable view of the market is perfectly rational.

Applying The Characteristics To Specific Projects

Given a large number of potentially productive projects, it is suggested that NASA attempt to determine those projects

most likely to be affected by one or more of the characteristics listed in Table 5.1. The greater the severity and the greater the number of characteristics exhibited by a potentially productive project, the more likely it is that the private sector will not invest in it and that it properly should be considered by NASA.

In order to implement the use of these characteristics, we suggest that technical committees which already advise NASA on project selection consider additionally the following simple questions:

- Is the technology sufficiently well defined so that a firm could plan to include it in its product concepts covered by its strategic plan?
- Is the technical risk of the project significantly greater than is typical for projects at the same R&D stage?
- Is the expected payback period beyond the normal product life cycle for similar products or technologies?
- Is the project significantly larger than those undertaken by firms at the same R&D stage?
- Are private firms likely to be able to capture sufficient benefits from the results to pay for investment in the project?

It is the interaction of these characteristics for particular technologies which is likely to determine whether or not they will be undertaken in the private sector.

In making these assessments, there are no hard and fast rules. For example, the duration of payback that a firm is willing to accept depends upon the life cycle of its products. An engine manufacturer is much more likely to expend its resources on a new material for turbines that may not pay off for fifteen years, than a new electronic control with a payback half as long. The life cycles for electronic parts are typically far too short to allow such long investment horizons.

It is outside the scope of this study to provide more than the characteristics of projects in which the private sector is unlikely to invest. But we are concerned especially about the willingness of the private sector to invest in one type of R&D--radically new technologies that would require wholesale changes in large systems. Structural ceramics in turbines is one such example. Typically, <u>because they would not be relevant to existing product concepts, such radical technologies would often be unlikely to get out of the basic or most fundamental applied levels of research</u>. Funding levels would most likely be small. Furthermore, the ultimate commercialization of such technologies would almost inevitably require technology demonstrations since wholesale changes in large systems would need to be tested in full scale configurations before being considered for certification and commercialization. It is extremely unlikely

that the private sector would fund a technology demonstration of a radically new technology if substantial technical risks remain.

Hazarding answers to our own questions with regard to structural ceramics, at their present stage of development:

- o Firms do not currently include the technology in their product concepts.
- o The technical risk in commercial figurations would seem to be high; currently, for example, the systems are not reliable for one-time use in cruise missiles.
- o The technology appears to be about 20-30 years from commercialization, well beyond the 15 year duration of even the longest corporate planning horizons.
- o The size of the project at each stage in the R&D process may exceed that which is typical.
- o The technology does not appear to be well enough developed to even hazard a guess as to ultimate capturability of benefits to the first firm to enter the market, but the present early experiments would seem to have wide applications, including to automobiles, and so are not likely to be capturable solely to aeronautics firms. Indeed, the Japanese are funding a cooperative research program in this area which includes both automobile and aeronautics firms.

These attributes of structural ceramics projects, assuming their technical merit and social value, would seem to make them candidates for NASA funding.

We suggest that the application of these questions to other emerging aeronautics technologies will aid NASA in making appropriate funding decisions.